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Evaluating the operation of three air cleaners working individually in a clean room

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SUMMARY
The use of portable air cleaners is becoming increasingly popular in many countries including Denmark. Portable air cleaners are known for not only removing but also generating particles and gases. To clarify this, three air cleaning technologies were evaluated. They were non-thermal plasma, photochemical air purifier and corona discharge ionizer. The concentrations of ultrafine particles, ozone and total volatile organic compounds were measured both in a duct and in a clean room. It was found that the studied air cleaning technologies increased the ozone level in the clean room and the duct. The increase of ozone level in the clean room was more than that was measured in the duct. Additionally, it was found that the number of ultrafine particles in the room increased due to the generated ozone. The number of generated particles changed with the season. The study leads to the recommendation that air cleaners should be evaluated in a clean room about generation of ozone to get more reliable evaluation.

IMPLICATIONS
The study showed that ozone even at low levels can generate particles and decrease air quality as a consequence. Particles influence human health. The study provided suggestions for future development of a standard testing procedure.

KEYWORDS

Air cleaner; Ozone; Particle

INTRODUCTION
Numerous air pollutants exist in the indoor air. Indoor air pollutants include gasses and particles. Depending on their diameters, the particles are divided into coarse particles, fine particles and ultrafine particles. Ultrafine particles can have adverse effects on human health. Because of their size, they lodge deep in the respiratory system and deposit in the lungs (Alessandrini et al. 2006).

Similarly, different gasses exist that are considered to be pollutants including CO2, CO and ozone. Ozone is a gas that absorbs ultraviolet light from the sun in the stratosphere and it constitutes an essential part of living conditions on earth. But, exposure to high concentrations of ozone in the inhaled air can have a hazardous effect on living organisms. The ozone concentration depends on outdoor air pollution of the place we live, and it is typically ten parts per billion (ppb) in an ordinary house (Johnson et al. 2001).

Different methods exist for reducing pollutants in buildings – e.g. source control, ventilation control and use of air-cleaning devices. The aim of air-cleaning technologies is to clean the indoor air and reduce the amount of supply air in a ventilation system. Different air-cleaning technologies have been invented and introduced on the market. Manufacturers claim that these technologies can remove pollutants, including ultrafine particles. However, some evaluations have shown results that differed from those of the manufacturers. In addition, studies have revealed that some air-cleaning technologies can themselves generate substances (Waring et al. 2008).

Accordingly, there is not enough reliable information about the efficiency and performance of the air-cleaning technologies in a room. The most evaluations have implemented in a duct. The aim of this study is to evaluate different air-cleaning technologies regarding their influence on the air quality, under conditions where they work continuously in a clean room.

METHODS

Three different portable air cleaners were evaluated. At the first step, the cleaning potential of the cleaners was tested in a duct. Then the measurements on the air cleaners were made in a room with a low level of ultra fine particles (clean room). The clean room was used to have control over measurement situation and the variables and reduce uncertainties. The dimensions of the clean room were 5.2m×2m×2.9m. The supply air was cleaned by different types of filters. The walls of the clean room were made of steel and glass. Two inlets were used for supply air and the air change rate of the room was about 3 h^{-1}. One by one, each air cleaner was placed in the middle of the room 1 m above floor level. The measurements were made at a distance of 1 m from the air cleaner. The clean room was pressurised in order to prevent infiltration. The room had a displacement ventilation system with an exhaust at the ceiling. The temperature and humidity of the clean room were measured during all measurements.

The air change rate of the room was obtained by measuring the decay of a tracer gas (Heidt and Werner, 1986). In order to ensure the cleanliness of the surfaces inside the room, the walls and the floor were cleaned by water one day prior to the day of every measurement.

The indoor ozone concentration was measured by using the ozone monitor BMT 930. The ozone concentration of the supply air was measured by the ozone monitor 2B Technologies Model 205. The concentration of ultrafine particles inside the room was measured by means of a NanoTracer PNT 1000. The concentration of ultrafine particles in the supply air was measured continuously using a Condensation Particle Counter (CPC) TSI model 3007. Using a multi-gas monitor from B&K, model 1302, the level of carbon monoxide (CO), carbon dioxide (CO2), water vapour and total volatile organic compounds (TVOC) were measured continuously during all measurements inside the room. An Innova model 1312 multi-gas monitor was used to measure concentration of different gases in the supply air.

The characteristics of the air cleaners are listed in Table 1. The PAP generates the ozone by an ozone generator and the concentration of ozone inside the device was about 100-1000 ppb; but it has an ozone filter to prevent the ozone coming out.

Table 1. The characteristics of the studied air cleaners

Air cleaners	Power(W)	Nominal Flow rate(m^3/h)
Non Thermal Plasma	40	140
Portable Air Purifier	135	43
Chorona Discharge Ionizer	55	300

In all measurements in the clean room, first the background level of ultrafine particles and gasses for the indoor air and the supply air were measured. The next step was that one of the three air cleaners was turned on to run continuously for hours. The air change rate of the room was measured in some of the tests.

RESULTS

The data of the duct measurements was shown in Table 2. As it is shown, the air cleaners reduced the UFP concentrations. Also, the concentration of ozone increased at the maximum 4 ppb. The data shown in the table is the mean of the data collected in the period of measurements.

Table 2. Concentrations of UFP and ozone for the air cleaners in the duct measurement

Air cleaners	Ozone concentration(ppb)		UFP concentration(UFP/cm^3)	
	Inlet	Outlet	Inlet	Outlet
NTP	9	13	5100	4300
CDI	9	12	5000	1100
PAP	9	10	5000	1000

The results of the concentrations of UFP and ozone, when Non Thermal Plasma (NTP) was tested in the clean room, are shown in Figure 1. The measurement was carried out during the summer season. The air cleaner was turned on during the rest of the measurement. The result showed that the concentration of ozone increased after the NTP was turned on at 11:00 am. The concentration of ultrafine particles increased about 1 hour after the start time.

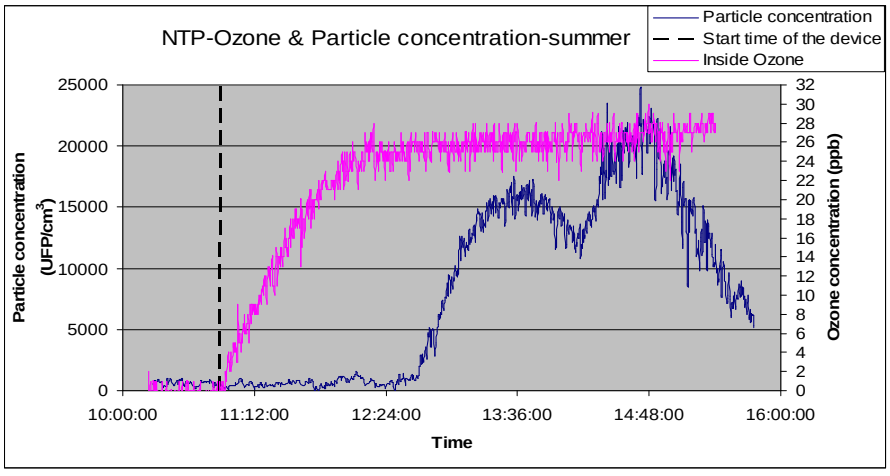

Figure 1. Concentration of particle and ozone for NTP in the clean room in summer

Concentration of the ozone was shown in ppb. The ozone concentration was increased by running the air cleaner, and ultimately it reached a steady-state concentration of 28 ppb. The concentration of ultrafine particles showed a different trend. The concentration of UFP increased to a maximum of 20,000 (UFP/cm^3) and then decreased to 5000 (UFP/cm^3).

Figure 2 shows the results for the autumn when the NTP was tested in a clean room. The maximum concentration of ozone reached the same level as for the summer. However, the concentration of ultrafine particles reached a maximum of 3500 (UFP/cm^3) which is approx. 80% lower than the summer measurements. The increase in the particle level started 2 hours after starting the air cleaner, i.e. 10:20. The changes in the level of UFP were the same as the summer measurement.

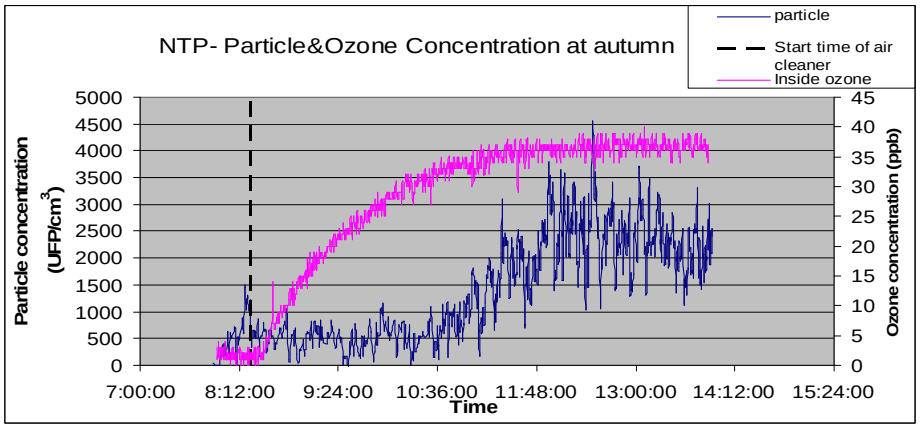

Figure 2. Concentration of particles for NTP in the clean room in autumn

Figure 3 shows the measurement of the concentrations of UFP and ozone when PAP tested in the clean room. The increase in the ozone concentration in the room was less than 9 ppb.

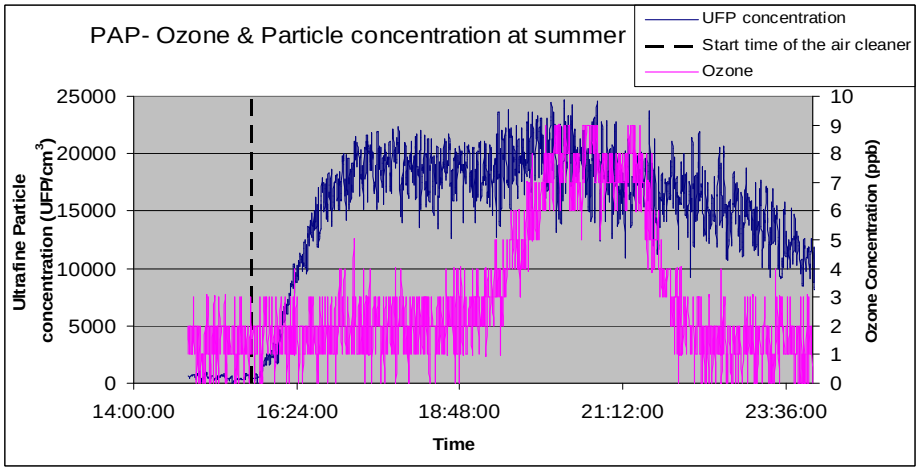

Figure 3. Concentration of UFP and ozone for PAP in a clean room in summer

An increase in the concentration of ultrafine particles was detected immediately after turning on the air cleaner. It reached the maximum concentration at around 23,000 (UFP/cm^3) and then decreased, but never reached at background level. The measurement was repeated in the autumn season and the maximum concentration of UFPs was less than 5,000 (UFP/cm^3).

A similar procedure was carried out for the third technology, i.e. Corona Discharge Ionizer. The ozone level started to increase when the air cleaner was turned on. The ozone reached a maximum concentration of 35 ppb and remained at that level during the measurement. Concentration of UFP did not show a significant increase and there were some fluctuations in the concentration. The maximum concentration of UFP was approx. 1000 (UFP/cm^3). The UFP levels and the ozone levels in both summer and autumn were similar.

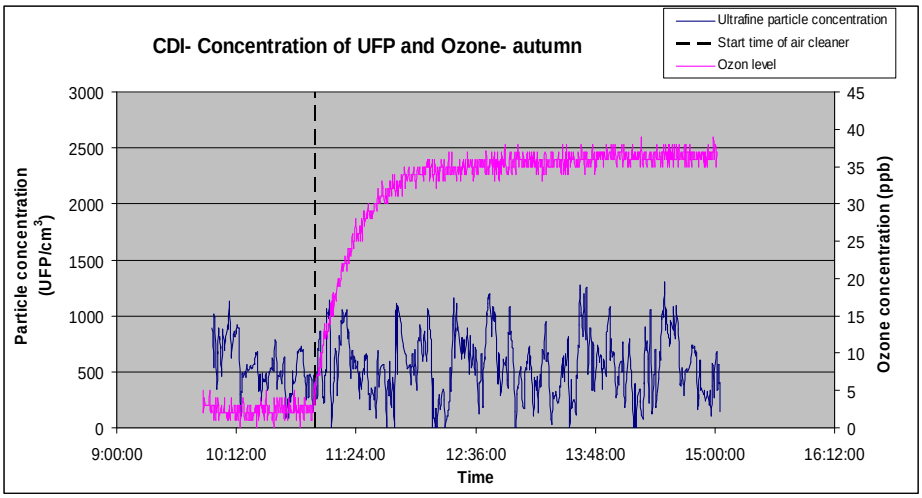

Figure 4. Concentration of particle and ozone for CDI in a clean room in summer

DISCUSSION

Three different technologies were tested and evaluated in this study. All three technologies increased the concentration of ozone in a clean room. The increased level of ozone in the room was higher than that shown by the duct measurements shown in Table 2. So the measurements made in the duct cannot show all the impacts of the air cleaners. The PAP increased the ozone concentration less than 8 ppb. The PAP and NTP technologies caused increases in the ultrafine particle concentration. PAP had an important advantage in that it only caused a very small increase in the concentration of ozone inside the room and it could reduce the concentration of fine particles.

As a hypothesis one mechanism that increased the level of UFP in the room may have been secondary formation of particles since the organic compounds might have reacted with generated ozone. The air contains organic compounds that are generated by different sources such as plants and that had entered the clean room with the supply air. Previous research studies show that Limonene and α-Pinene can react with ozone and cause generation of ultrafine particles (Yokouchi and Ambe, 1985). The difference in the UFP concentration at different seasons may be explained by the level of TVOC emitted by plants. The rate of TVOC emitted by plants is related to light intensity (Owen et al. 2002).

Another hypothesis is that ultrafine particles are generated because of the reaction of the TVOC adsorbed on the surfaces with the ozone that was generated by the air cleaners. In the case of the PAP technology, the air cleaner had a high level of ozone inside the device, but not outside the device. So, if this hypothesis is correct, then the particles are generated inside the PAP. A possible way of eliminating the problem is to improve its precipitator. CDI did not increase the concentration of UFP. One hypothesis for CDI is that the air cleaner itself removes the generated particles.

The first hypothesis appears to be the more reliable, since we can conclude from the figures that there is a maximum for the UFP concentration. The concentration of UFP decreased gradually and then continued until reaching steady-state. There seem to be specific substances in the air that reacted when the air cleaners were present. According to the figures, after having at least a minimum of ozone level, the concentration of UFP starts to increase. This effect can not be seen in the duct measurements. Additional evaluation will be done in an ordinary office to evaluate if there is similar increase in the concentrations of ozone and ultrafine particles.

CONCLUSIONS

The evaluation shows that measurements in a duct do not show all the impacts of an air cleaner. It is recommended to evaluate an air cleaner in a clean room in order to study the influence of it on the concentrations of UFP and ozone. The study showed that the technologies, Corona Discharge Ionizer, Non Thermal Plasma and Photochemical Air Purifier, can increase the level of ozone inside a room. According to this study, more investigations are needed on air cleaners dealing with ozone in order to assess their influence on the UFP concentration. Also, more evaluations are needed regarding the relation between the generated particle level and different seasons.

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REFERENCES

Alessandrini F., Schulz H., Takenaka S., Lentner B., Karg E., Behrendt H. and Jakob T. 2006 Effects of ultrafine carbon particle inhalation on allergic inflammation of the lung. Journal of Allergy and Clinical Immunology, 117 (4), pp. 824-830

EIA. 2010. International Energy Outlook. Office of Integrated Analysis and Forecasting: U.S. Energy Information Administration.328 pages.

Heidt F. D. and Werner H. 1986. Microcomputer-aided Measurement of Air Change Rates. Energy and Building, 9 (4) 313–320.

Jonson J. E., Sundet J. K. and Tarrasón L. 2001. Model calculations of present and future levels of ozone and ozone precursors with a global and a regional model. In Proceeding of: Atmospheric Environment, 35(3), pp. 525-537.

Owen S. M., Harley P., Guenther A., Hewitt C. N. 2002. Light dependency of VOC emissions from selected Mediterranean plant species. Journal of Atmospheric Environment, 36(19), pp.3147-3159.

Waring M. S., Siegel J. A., and Corsi R. L. 2008. Ultrafine Particle Removal and Generation by Portable Air Cleaners. Atmospheric Environment, 42(20), pp. 5003–5014.

Yokouchi Y., Ambe Y. 1985. Aerosols formed from the chemical reaction of monoterpenes and ozone. Atmospheric Environment 19(8), pp. 1271-1276.